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International Physical Activity and Built Environment Study of adolescents: IPEN Adolescent design, protocol and measures

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ABSTRACT

Introduction Only international studies can provide the full variability of built environments and accurately estimate effect sizes of relations between contrasting environments and health-related outcomes. The aims of the International Physical Activity and Environment Study of Adolescents (IPEN Adolescent) are to estimate the strength, shape and generalisability of associations of the community environment (geographic information systems (GIS)-based and self-reported) with physical activity and sedentary behaviour (accelerometer-measured and self-reported) and weight status (normal/overweight/obese).

Methods and analysis The IPEN Adolescent observational, cross-sectional, multicountry study involves recruiting adolescent participants (ages 11–19 years) and one parent/guardian from neighbourhoods selected to ensure wide variations in walkability and socioeconomic status using common protocols and measures. Fifteen geographically, economically and culturally diverse countries, from six continents, participated: Australia, Bangladesh, Belgium, Brazil, Czech Republic, Denmark, Hong Kong SAR, India, Israel, Malaysia, New Zealand, Nigeria, Portugal, Spain and USA. Countries provided survey and accelerometer data (15 countries), GIS data (11), global positioning system data (10), and pedestrian environment audit data (8). A sample of n=6950 (52.6% female; mean age=14.5, SD=1.7) adolescents provided survey data, n=4852 had 4 or more 8+ hours valid days of accelerometer data, and n=5473 had GIS measures. Physical activity and sedentary behaviour were measured by waist-worn ActiGraph accelerometers and self-reports, and body mass index was used to categorise weight status.

Ethics and dissemination Ethical approval was received from each study site's Institutional Review Board for their in-country studies. Informed assent by adolescents and consent by parents was obtained for all participants. No personally identifiable information was transferred to the IPEN coordinating centre for pooled datasets. Results will be communicated through standard scientific channels and findings used to advance the science of environmental correlates of physical activity, sedentary behaviour and weight status, with the ultimate goal to stimulate and guide actions to create more activity-supportive environments internationally.

Strengths and limitations of this study

- This study will provide a comprehensive assessment across 15 countries of the built environment (self-reported, observational audits and geographic information systems) and physical activity and sedentary behaviours (self-report, accelerometer) which should allow for a more robust estimation of associations between the built environment and physical activity, sedentary behaviour and weight status in adolescents than has been possible in past studies.
- Recruiting participants living in neighbourhoods stratified by walkability and socioeconomic status will ensure a wide range of variability in built environment characteristics both within and across countries.
- The inclusion of 15 countries in 6 continents with diversity of income, culture and geography, including low-income countries, will provide a robust evaluation of the generalisability of results across countries.
- All 15 countries collected data according to a common protocol and all data will be processed at the coordinating centre to ensure comparable scoring methods.
- This is an observational, cross-sectional design which cannot provide evidence of causality.

INTRODUCTION

In the last 40 years, there have been sixfold and eightfold increases in age-standardised obesity globally among girls and boys, respectively.[1] Adolescents who meet physical activity

(PA) guidelines (60 min of moderate-to-vigorous physical activity (MVPA) daily) are less likely to be obese, and have other cardiometabolic risk factors.[2] They are also more likely to have better mental health[3] and be physically active adults.[4] A systematic review of device-based sedentary behaviour found inconsistent associations with health outcomes in children and adolescents,[5] but there is stronger evidence linking recreational screen time with obesity.[6] Most health authorities recommend limiting recreational screen time in children and adolescents to no more than 2 hours/day,[7] but they do not have specific guidelines for overall sedentary behaviour.

The global prevalence of adolescents meeting PA guidelines is low. A recent pooled sample of survey data from 1.6 million adolescents across 146 countries reported approximately 4 of 5 adolescents did not meet PA guidelines.[8] Data from the 73 countries which also provided data on 15-year changes in prevalence revealed no improvement for boys or girls. The most recent estimate from 49 countries was that only 34%–39% of children and adolescents are meeting screen time recommendations.[9]

Environmental and policy interventions for promoting PA, reducing sedentary behaviour and preventing obesity have been widely recommended by health agencies globally.[10–17] Recommended built environment changes, such as designing neighbourhoods where residents can walk or bike to shopping, school and recreation facilities, as well as providing safe facilities for walking and bicycling should be evidence based. However, the potential effects of the built environment on PA, sedentary behaviour and obesity are less understood in youth than adults.[18]

An umbrella review of 10 systematic reviews of PA correlates among children and adolescents found a lack of consistency in environmental correlates of adolescents' PA.[19] Only two reviews reported positive associations between proximity of exercise facilities and youth PA,[20 21] and two other reviews reported no associations.[22 23] Ding *et al*[24] found in their review that the mode of assessment influenced the findings with measures of built environments obtained from geographic information systems (GIS) more likely to identify significant associations.

Correlates of adolescents' sedentary behaviour have primarily focused on screen time[25] with few studies examining built environmental features and sedentary behaviour. In a recent review, psychological correlates have not been widely studied, and in the few studies, neighbourhood PA environment were rarely related to screen time or sedentary behaviours in youth.[6] The strongest evidence is that televisions, computers and gaming systems in adolescents' bedrooms is related to more screen time.[6 26 27]

There are major limitations with the evidence to date on environmental correlates of PA, sedentary behaviour and weight status in youth: (1) most studies have been performed in North America, Australia and Europe; (2) there is a lack of consistency in the measures used; (3) many studies have been underpowered; and (4) most studies have been conducted within a single country which can result in reduced heterogeneity of built environment and therefore difficulty in detecting meaningful associations.[28 29] To accurately assess the strength of association of the built environment with PA, sedentary behaviour and weight status, greater environmental variability is required than any one country can provide. There is a need for a coordinated international study that examines generalisable environmental correlates of adolescent PA, sedentary behaviour and weight status that can provide maximum variation between and within countries.

IPEN ADOLESCENT STUDY AIMS

The International Physical Activity and Environment Study of Adolescents (IPEN Adolescent) was designed to overcome many of the limitations identified in the literature. The primary aims of IPEN Adolescent are to estimate strength, shape and generalisability (across cities) of associations of GIS-based and reported measures of the neighbourhood environment with accelerometer-measured minutes of MVPA and sedentary behaviour, along with multiple reported PA indices in adolescents aged 11–19 years. Secondary aims of IPEN Adolescent are to estimate strength, shape and generalisability of associations of GIS-based and reported measures of neighbourhood environments with weight status (normal, overweight, obese) in adolescents. Tertiary aims are to examine: (1) the unique contribution of GIS-based and reported measures of built environment attributes explaining PA, sedentary behaviour and weight status in adolescents; (2) mediating effects of device-based MVPA and sedentary behaviour on the relation between GIS-based and reported environment attributes and weight status; (3) moderating effects of neighbourhood socioeconomic status (SES) and sex on the relation between objective and reported community environment attributes and PA, sedentary behaviour and weight status outcomes; and (4) the combined and interactive effects of psychosocial variables (social support, self-efficacy, barriers), home environment variables (sport equipment, electronics) and community environment variables in explaining PA and sedentary behaviours. The purpose of the present paper is to describe the IPEN Adolescent study methods, protocols, measures, planned analyses and dissemination plans.

IPEN ADOLESCENT STUDY DESIGN AND OVERVIEW

The IPEN Adolescent study was an observational, cross-sectional, multicountry study with purposive sampling. The goal was to implement comparable methods and measures across diverse countries so data could be pooled across countries for analyses. A coordinating centre (CC) based in San Diego, USA developed methods for monitoring comparability of methods and ensuring quality of all measures, similar to the approach used in the IPEN Adult study.[30] However, given the realities and constraints of collecting data on six continents, there were variations in methods. The overall methods and their variations are reported in the present paper.

Adolescents, aged 11–19 years, along with one parent/guardian, from 15 geographically and culturally diverse countries were recruited directly from neighbourhoods or via schools with the aim of ensuring they lived in administrative units (AUs; eg, census tracts, meshblocks; termed 'areas') that varied in walkability and SES. Neighbourhoods were stratified into four neighbourhood types (called study design quadrants): high walkability-high SES, high walkability-low SES, low walkability-high SES and low walkability-low SES. High-walkable and low-walkable and high-SES and low-SES areas were defined as described in table 1 to achieve wide variation within countries. Participating adolescents were asked to wear accelerometers for at least 7 days and completed a survey that included environmental variables, PA and sedentary behaviour outcomes, height/weight and psychosocial variables.

The IPEN Adolescent study was based on the study-specific ecological model depicted in figure 1. At the left of the figure are the distal influences such as SES, expected to affect and interact with proximal influences. The second column has behaviour-specific proximal influences at the individual, social and built environment levels. It was anticipated that specific associations of proximal influences would affect and interact with specific behavioural outcomes as indicated, with interactions across levels (not illustrated). Behavioural outcomes were selected because of their relevance to multiple adolescent health indicators[31 32] though body mass index (BMI) was the only health outcome assessed by all countries.

Recruitment of countries and inclusion criteria

To achieve a diverse set of participating countries that would maximise variability in built environments, investigators were invited to complete applications for inclusion in the IPEN Adolescent grant proposal. Invitations to apply were sent by email to about 400 people who had registered on the IPEN website (www.ipenproject.org). Interested investigators provided information about such issues as country to be represented, city(ies) from which adolescents would be recruited, availability of GIS data related to walkability, training and experience with PA and built environment research of key investigators, list of relevant publications, potential to apply for study funding within the country, and willingness to contribute data for international pooled analyses. An international Executive Committee reviewed the applications and selected investigators who best met these criteria for inclusion in the grant proposal to the US National Institutes of Health (NIH):

- Environmental variability: ability to recruit and collect data from adolescents (11–19 years of age) residing in areas varying in walkability and SES, defined using GIS and census data.
- Number of participants: the countries were instructed to aim for at least 300 participants contributing accelerometer data, built environment data and PA surveys.
- Primary investigator qualifications and experience: investigators were accepted who demonstrated the highest academic qualifications and experience either through participation in the IPEN Adult study or use of similar protocols for neighbourhood selection procedures, participant recruitment, accelerometer data collection, quality control and data management, as well as creation of GIS variables that could be applied in the IPEN Adolescent study. Countries that did not have the capacity to create GIS variables but met the other criteria were included in the study as 'exploratory' countries. Exploratory countries were asked to aim for recruiting at least 150 participants with survey and accelerometer data.
- International diversity: there was a goal to represent all inhabited continents in IPEN Adolescent, with countries ranging from low income to high income.

In the grant proposal, data collection in seven countries was to be funded by the NIH grant, with eight additional countries obtaining their own funding. Ultimately, 15 countries from 6 continents completed data collection and contributed data (table 2, figure 2). Two of the countries were low income (Bangladesh, Nigeria) and three were middle income (Brazil, India, Malaysia).

National variability in economic, population and health indicators across countries represented within IPEN Adolescent is shown in table 1. Data were sourced from websites that compile international statistics (eg, WHO, Global Observatory on PA). The gross domestic product per capita in 2017–2018 US dollars ranged from US$4200 (Bangladesh) to US$64 500 (Hong Kong). Obesity rates for adolescents ranged from 1.3% (Nigeria) to 22.3% (USA) for males and 1.1% (India) to 19.0% (USA) for females. Life expectancy ranged from 54.8 (Nigeria) to 84.8 (Hong Kong) years while deaths from non-communicable diseases ranged from 29% (Nigeria) to 91% (Spain). The prevalence of adolescents meeting PA guideline ranged from 8.4% (Hong Kong) to 33.5% (Bangladesh), while deaths related to physical inactivity ranged from 1.3% (Nigeria) to 16.4% (Malaysia). Population per square kilometre ranged from 3.3 (Australia) to 6756.7 (Hong Kong). Finally, car ownership per 1000 population ranged from 4 (Bangladesh) to 860 (New Zealand).

Study design criteria and neighborhood/school selection

To meet study goals of achieving broad variability in built environments, and avoiding confounding of built environments and SES, walkability and SES indicators were used a priori to select neighbourhood areas that met criteria for the four quadrant types noted above. Then, depending on the recruitment methods used in each country (see next section), households and/or schools were identified within the quadrants for targeted recruitment procedures.

Table 1 Study details and national statistics for 15 International Physical Activity and Environment Study of Adolescents (IPEN Adolescent) countries[92–128]

	Australia	Bangladesh	Belgium	Brazil	Czech Republic	Denmark	Hong Kong SAR	India	Israel	Malaysia	New Zealand	Nigeria	Portugal	Spain	USA
Principal Investigator(s)	Salmon and Timperio	Islam	Van Dyck	Reis	Mitáš and Frömel	Troelsen	Cerin	Anjana	Epel	Manan	Hinckson	Oyeyemi	Mota and Santos	Molina-García and Queralt	Sallis
Funding sources	National Heart, Lung, & Blood Institute (R01 HL11 1378)	National Heart, Lung, & Blood Institute (R01 HL11 1378)	Research Foundation Flanders (FWO12/ASP/102) and National Heart, Lung, & Blood Institute (R01 HL11 1378)	The Brazilian National Council for Scientific and Technological Development (306836/2011-4) and National Heart, Lung, & Blood Institute (R01 HL11 1378)	Czech Science Foundation and Faculty of Physical Culture GA14-26896S and GA17-24378S	Faculty of Health Science, SDU and National Heart, Lung, & Blood Institute (R01 HL11 1378)	Health and Medical Research Fund – Hong Kong SAR 10111501 and National Heart, Lung, & Blood Institute (R01 HL11 1378)	Madras Diabetes Research Foundation	Israel Science Foundation (916/12).	Universiti Sains Malaysia International Research Collaboration Grant (IReC) and National Heart, Lung, & Blood Institute (R01 HL11 1378)	Health Research Council of New Zealand (HRC12/329)	National Heart, Lung, & Blood Institute (R01 HL11 1378)	Research Centre (CIAFEL) supported by FCT (Portuguese Foundation for Science and Technology)	Generalitat Valenciana, Spain GV-2013-087	National Heart, Lung, & Blood Institute (R01 HL083454 and R01 HL111378)
Study name	NEArbY Study	IPEN-Adolescent Bangladesh	IPEN-Adolescent Belgium	ESPACOS-adolescentes	IPEN Adolescent: International research of Built Environment and Physical Activity	IPEN-Adolescent Denmark	iHealt(H)	BE ACTIV INDIA !	IPEN – Adolescent Israel	IPEN Adolescent: Study of Built Environment and Physical Activity	Built Environment and physical Activity in New Zealand adolescents	IPEN Adolescent-Nigeria	IPEN-Adolescent Portugal	IPEN Adolescent-Spain	Teen Environment and Neighborhood Study
Study-specific publications (up to 5)		Islam *et al*, 2016[92]		Alberico *et al*., 2017[93]; Prado *et al*, 2017[94]	Rubin *et al*, 2018[95]		Cerin *et al*., 2014[96]; Cerin *et al*., 2017[97]; Cerin *et al*., 2019[98]; Barnett *et al*., 2019[99]; Barnett *et al*, 2019[100]		Moran *et al*., 2015[101]; HaGani *et al*, 2019[102]		Hinckson *et al*., 2014[103]; Schofield *et al*., 2015[104]; Hinckson *et al*, 2017[105]		Pizarro *et al*., 2016[106]; Pizarro *et al*, 2017[107]	Molina-Garcia *et al*., 2017[108]; Aznar *et al*., 2018[109]; Estevan *et al*., 2018[110]; Molina-Garcia *et al*., 2019[111]; Queralt *et al*, 2019[112]	Carlson *et al*., 2015[113]; Carlson *et al*., 2017[114]; Wang *et al*., 2017[115]; Borner *et al*., 2018[116]; Sallis *et al*, 2018[117]
GDP per capita in 2017–2018 US dollars[118]	50,400	4200	46 600	15 600	35 500	50 100	64 500	7200	36 400	29 100	39 000	5900	30 500	38 400	59 800
Obesity rates % BMI >2 SD above the median (ages 10–19)[119]	Males: 12.2 Females: 10.4	Males: 2.3 Females: 1.8	Males: 7.2 Females: 4.9	Males: 10.1 Females: 7.8	Males: 10.7 Females: 5.3	Males: 8.2 Females: 4.0	Males: 11.8 Females: 4.7 (China)	Males: 1.8 Females: 1.1	Males: 12.2 Females: 8.0	Males: 13.5 Females: 9.3	Males: 15.8 Females: 14.1	Males: 1.3 Females: 1.8	Males: 8.7 Females: 8.2	Males: 10.6 Females: 6.3	Males: 22.3 Females: 19.0
Life expectancy in years[120]	82.6	72.2	80.9	74.9	78.6	80.9	84.8[121]	68.5	82.1	75.1	82.0	54.8	81.3	82.7	78.6
% of deaths from non-communicable diseases[122]	90	67	86	74	90	90	59[123]	63	86	74	90	29	86	91	88
Prevalence of meeting PA guidelines in adults (%)[124]	43	73	67	72	76	76	40	87	32	48	52	78	65	70	68
Prevalence of meeting PA guidelines in adolescents[125]	11.1	33.5	16.5	16.3	22.5	15.6	8.4[126]	25.9	15.4	13.8	11.4	No data	15.7	23.2	27.7

Continued

Table 1 Continued

	Australia	Bangladesh	Belgium	Brazil	Czech Republic	Denmark	Hong Kong SAR	India	Israel	Malaysia	New Zealand	Nigeria	Portugal	Spain	USA
% of deaths related to physical inactivity[124]	10.1	1.3	11.4	13.2	6.7	9.4	No data	4.2	No data	16.4	12.7	No data	13.6	13.4	10.8
Population per sqkm[127]	3.3	1249.5	387.1	25.3	138.5	138.3	6756.7	446.0	403.6	99.4	18.6	235.0	112.6	100.2	36.1
Motor vehicles per 1000 people[128]	730	4	508	350	539	438	92	22	384	433	860	64	492	648	838

Country-level data collection dates may not necessarily coincide with the country level attribute data presented in this table.
BMI, body mass index; GDP, gross domestic product; PA, physical activity.

To assess the walkability of AUs for stratification and selection, all countries except for Malaysia, India and Nigeria used GIS data to construct a walkability index that was a composite of residential density, intersection density and land use mix, similar to what has been used in earlier studies.[33–35] Malaysia used a composite measure of residential and intersection density, but did not have GIS-based land uses. India and Nigeria did not have GIS data, but instead categorised areas as low or high walkable based on judgments by study investigators and local land-use experts who were familiar with the walkability index (table 3).

The SES of areas was classified as low or high based mainly on country-specific demographic data from various sources, as indicated in table 3. India and Nigeria categorised their AUs as low or high income based on investigator judgments. Most countries with computed area-level walkability and SES measures used city/region-specific median values to classify eligible areas into low versus high groups and cross-classify into one of the four quadrants for walkability by SES. However, several countries used more stringent criteria for specifying eligibility of areas in quadrants by excluding areas in the highest, lowest, and/or middle deciles of walkability and SES scores, as has been done in previous studies.[33]

Participant recruitment

There were two primary strategies for the identification and recruitment of adolescents and one parent/guardian (except New Zealand, which recruited adolescents only): (1) recruitment by residential address in preselected areas, and (2) recruitment by school attended. The first was a systematic selection of participants identified as living at an address within an eligible area located in one of the four walkability-by-SES quadrants. Three countries (Brazil, Israel, USA) used this method of recruitment exclusively to recruit participants. Belgium and India used the residential address method to recruit some participants, but also recruited other participants from preselected schools stratified by quadrant based on its location.

The other 10 countries used the second strategy of recruiting participants through schools. Schools were preselected based on locations stratified into one of the four walkability-by-SES quadrants. Countries using this method were mindful of balancing both the number of schools and number of participants recruited from them, such that both were roughly comparable across the four quadrants. Recruitment within schools used methods such as random sampling and whole classroom recruitment. Students were recruited either because it was known they lived in quadrant-specific targeted areas, or the student's residential address was checked following recruitment or data collection and assigned the appropriate quadrant code for the area in which they lived.

All countries conducted recruitment in person (at schools and/or residences), except for the USA, which used telephone and mail methods of recruitment. Some

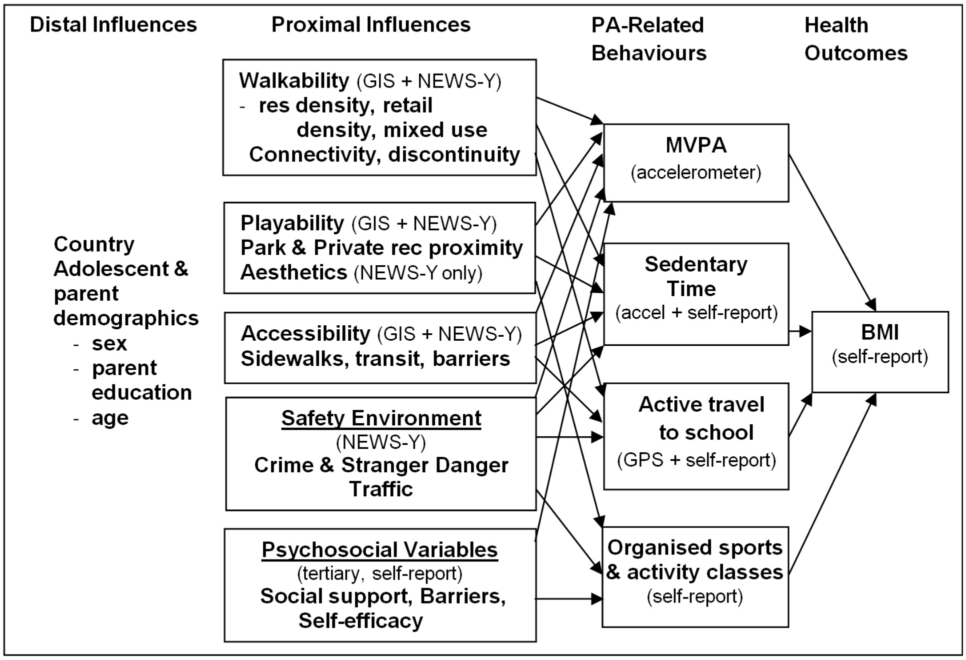

Figure 1 Ecological model for the International Physical Activity and Environment Study of Adolescents study. BMI, body mass index; MVPA, moderate-to-vigorous physical activity; GIS, geographic information systems; PA, physical activity.

countries identified eligible addresses using commercial and government sources and randomly selected households to contact from these databases, while others used a door-to-door method of recruitment. For door-to-door methods, standard procedures for systematically sampling households were employed.[36 37]

Table 2 International Physical Activity and Environment Study of Adolescents study locations, sample sizes and income status

Country	Cities	N	Income status
Australia	Melbourne	438	High
Bangladesh	Dhaka	92	Low
Belgium	Ghent	291	High
Brazil	Curitiba	493	Middle
Czech Republic	Olomouc and Hradec Králové	338	High
Denmark	Odense	210	High
Hong Kong SAR (China)	Hong Kong	1295	High
India	Chennai	316	Middle
Israel	Haifa	232	High
Malaysia	Kuala Lumpur	752	Middle
New Zealand	Auckland & Wellington	648	High
Nigeria	Gombe	268	Low
Portugal	Gondomar, Matosinhos, Maia, Porto and Valongo	184	High
Spain	Valencia	465	High
USA	Baltimore and Seattle regions	928	High

Additional information such as recruitment dates, participation rates, age ranges of participants, school schedules, incentives and contact mode for each IPEN Adolescent country can be found in table 4.

Patient and public involvement

Patients or the public were not involved in the design, or conduct, or reporting, or dissemination plans of our research.

Measures

The main outcomes of IPEN Adolescent were PA and sedentary time measured by accelerometers and self-reports, as well as BMI. The main independent variables were built environment attributes around homes and schools relevant to PA for leisure and transportation purposes. The environmental measures used data found in GIS databases as well as social and built environment attributes around homes and psychosocial variables that were reported by parents and adolescents. Survey administration mode varied across countries, with eight countries conducting in-person interviews, six countries using a self-administration method of either paper or online questionnaires, and one country using both methods.

A comprehensive description of survey measures used is provided in table 5. The required core survey measures were the Neighborhood Environment Walkability Scale for Youth (adolescents and parents[29]; public transport use, active transport to/from school, barriers to active transport to school, overall PA at and outside of school, sports teams, psychosocial measures for PA (benefits, barriers, efficacy, social support, enjoyment), sedentary

Figure 2 Map of countries where the International Physical Activity and Environment Study of Adolescents study was conducted.

activities, personal electronics and electronics in the bedroom, home equipment for activity and sports, reasons for moving to a neighbourhood (to account for self-selection of neighbourhoods), and key demographics for the adolescent and parent. Other survey measures were recommended and collected in some countries. Virtually all survey measures have evidence of test–retest reliability and validity, though only in a few countries. Details about the survey measures can be found in table 5, and the surveys can be found here: https://www.ipenproject.org/methods_surveys.html#TranslatedAdol.

The availability of various survey methods and measures across countries is shown in online supplemental table 1). Survey and accelerometer data were collected in all 15 countries. GIS data were collected in 11 countries. Eight countries collected pedestrian environment data using the Microscale Audit of Pedestrian Streetscapes (MAPS Global[38]) tool, and 10 countries collected global positioning system (GPS) data (see table 6).

Device-based PA and sedentary time

Adolescents were asked to wear an ActiGraph accelerometer around the waist on a belt for at least seven complete days during waking hours when not swimming or bathing. Depending on device availability and data collection dates, various ActiGraph models were used (see online supplemental table 2 for details). Fourteen countries used a GT model (GT1M, GT3X, GT3X+), and one country primarily used the older generation 7164 model. The low frequency extension (LFE), which improves comparability between data collected with 7164 and the newer generation GT models,[39] was used in 12 countries that employed a GT model. One country used the LFE for about half of their sample. On retrieval of devices, data were screened for device malfunction and valid wearing time. To achieve a sufficient amount of data, participants with 4 or fewer wearing days were asked to rewear the accelerometer to achieve 7 wearing days. Practical considerations such as availability of devices compared with the length of the data collection timeline, as well as availability of staff to deploy 'rewear' accelerometers, resulted in variation in use of rewear methodology across countries.

Because of the wide variety of accelerometer data management and scoring procedures used,[40] all data were transferred to the CC for screening and processing to ensure comparable scoring methods. All data were collected with, or converted to, a 30 s epoch, and nonwear time was defined as 60 or more minutes of consecutive zero counts.[41] Wear time was calculated as the total amount of time in a day minus nonwear time. A valid wearing day contained at least 8 hours of wear time during waking hours from 06:00 to 12:00. Data were processed using MeterPlus V.5.0 applying Evenson cut points for PA and sedentary time.[42] To be included in analyses, at least 4 days of wear time were required.[40] See table 6 for accelerometer n's by country for 1+ valid days and 4+ valid days.

In addition to creating PA intensity variables for total accelerometer wearing time, accelerometer data were summarised for specific time periods: before, during and after school on school days and all time on 'non-school' days. A Saturday–Sunday weekend designation for non-school days did not apply because of the variability in school schedules across countries. Self-reported school start and end times were used in most countries to determine school days and in-school times. These data were not available in the USA; therefore, 08:15 to 14:15 was used as an estimate of the school day on weekdays. Days without reported school times were considered non-school days unless they did not fit the pattern of typical non-school days in the country (see table 3 for school schedules by country). In these cases, school start and end times were imputed using information from participants at the same school. School days were segmented into before school (06:00–school start), during school (school start–school end), and after school (school end–12:00). Wear time on non-school days was 06:00–12:00.

Accelerometer measures available for analyses are average minutes in sedentary, light, moderate and

Table 3 Neighbourhood selection criteria for 15 International Physical Activity and Environment Study of Adolescents countries

	Australia	Bangladesh	Belgium	Brazil	Czech Republic	Denmark	Hong Kong SAR	India
Recruitment units. # schools or admin units (if did not recruit through schools)	18 schools	6 schools	4 schools	40 census tracts	10 schools	8 schools	19 schools	157 wards
Walkability administrative unit (area)	SA1 (Statistical Area 1)	Wards	Statistical sectors	Census tracts	Cadastral Areas	Statistical Units	Tertiary Planning Units (TPUs)	Wards
Walkability index details	GIS: 5 land uses, intersection density, gross residential density, no retail FAR	GIS: 10 land uses, Intersection density, net residential density, land use mix no retail FAR	GIS: 5 land uses, Intersection density, net residential density, land use mix no retail FAR	GIS: 5 land uses, intersections density, net residential density, land use mix, retail density	GIS: 4 land uses, intersection density, net residential density, land use mix, retail FAR	GIS: 6 land uses, intersection density, net residential density, land use mix, retail FAR	GIS: 5 land uses, Intersection density, net residential density, land use mix No retail FAR	No GIS
Walkability criteria	Deciles 1–5 (low) Deciles 6 to 10 (high)	25th %tile and lower (low) 75th %tile higher (high)	Deciles 6–10 (low) Deciles 1 to 5 (high)	Deciles 2–3 (low) Deciles 8 to 9 (high	Deciles 1–4 (low) Deciles 7 to 10 (high)	Deciles 1–5 (low) Deciles 6 to 10 (high)	Deciles 1–5 (low) Deciles 6 to 10 (high)	High or low based on expert judgments by people familiar with GIS-based walkability components
SES criteria	Deciles 1–5 (low) Deciles 6 to 10 (high)	25th %tile and lower (low) 75th %tile and higher (high)	Deciles 6–10 (low) Deciles 1 to 5 (high)	Deciles 2–4 (low) Deciles 8 to 9 (high)	Deciles 2–4 (low) Deciles 7 to 9 (high)	Deciles 1–5 (low) Deciles 6 to 10 (high)	Deciles 1–5 (low) Deciles 6 to 10 (high)	High or low based on expert judgement
SES sources	Median household income from Australian Bureau of Statistics 2011	Education (literacy rate) from Bangladesh Bureau of Statistics 2011	Household income from city council Ghent 2012	Household income from Brazilian Institute of Geography and Statistics (IBGE) (http://www.ibge.gov.br/english/) 2010	Degree of education, rate of unemployment from Czech Census of Population and Housing 2011	Household income from Municipality of Odense 2013	Median household income at the TPU level from Census and Statistics Department—Hong Kong 2011	Expert judgments, using information about property values, aesthetics, building quality, to classify wards as low or high SES
# participants per quadrant	High walk/high SES=102 High walk/low SES=136 Low walk/ high SES=99 Low walk/low SES=101	High walk/ high SES:18 High walk/ low SES:25 Low walk/ high SES:23 Low walk/ low SES:26	High walk/ high SES: 45 High walk/ low SES:131 Low walk/ high SES:106 Low walk/ low SES: 9	High walk/high SES:105 High walk/low SES:149 Low walk/high SES:108 Low walk/low SES: 131	High walk/high SES: 99 High walk/low SES: 40 Low walk/high SES:59 Low walk/low SES: 140	High walk/ high SES: 48 High walk/ low SES:56 Low walk/ high SES: 65 Low walk/ low SES:41	High walk/high SES: 294 High walk/low SES:344 Low walk/high SES: 308 Low walk/low SES:349	High walk/ high SES: 75 High walk/ low SES: 88 Low walk/ high SES: 77 Low walk/ low SES: 76

	Israel	Malaysia	New Zealand	Nigeria	Portugal	Spain	USA
Recruitment units. # schools or admin units (if did not recruit through schools)	51 statistical areas	15 schools	8 schools	8 schools	6 schools	9 schools	447 block groups
Walkability administrative unit (area)	Statistical areas defined by the Israel Central bureau of statistics	Neighbourhood units	Meshblocks	Census enumeration areas	Census block groups 'Secção'	Census tracts	Census block groups (2000)
Walkability index details	GIS: 3 land uses, intersection density, net residential density, land use mix No retail FAR	GIS: no land uses, intersection density, net residential density, land use mix No retail FAR	GIS: 5 land uses, intersection density, gross residential density, land use mix No retail FAR	No GIS	GIS: 8 land uses, intersection density, net residential density, land use mix No retail FAR	GIS: 7 land uses, intersection density, net residential density, land use mix No retail FAR	GIS: 5 land uses, intersection density, net residential density, land use mix, retail FAR
Walkability criteria	Deciles 1–5 (low) Deciles 6 to 10 (high)	Deciles 1–5 (low) Deciles 6 to 10 (high)	Deciles 1–5 (low) Deciles 6 to 10 (high)	High or low based on expert judgments by people familiar with GIS-based walkability components	Deciles 1–4 (low) Deciles 7 to 10 (high)	Deciles 1–5 (low) Deciles 6 to 10 (high)	Deciles 1–4 (low) Deciles 7 to 10 (high)
SES criteria	Deciles 1–5 (low) Deciles 6 to 10 (high)	0 (low) 1 (high)	Deciles 1–5 (low) Deciles 6 to 10 (high)	High or low based on expert judgement	Deciles 1–4 (low) Deciles 7 to 10 (high)	Deciles 1–5 (low) Deciles 6 to 10 (high)	Deciles 1–5 (low) Deciles 7–9 (high)
SES sources	SES index of the Israeli Central Bureau of Statistics: composite measure: demographics, employment, income, education, car ownership, density. 2008	Self-reported Income 2015	Census median personal income from Statistics New Zealand 2006	National Population Commission	Education from the Portuguese Census 2011	Education from Spanish National Statistics Institute 2011	Median household income (2000 U.S. Census)
# participants per quadrant	High walk/high SES: 55 High walk/low SES:55 Low walk/high SES: 62 Low walk/low SES:60	High walk/high SES: 232 High walk/low SES:377 Low walk/high SES: 68 Low walk/low SES:75	High walk/high SES: 139 High walk/low SES: 189 Low walk high SES: 178 Low walk/low SES:142	High walk/ high SES: 15 High walk/ low SES: 131 Low walk/ high SES: 95 Low walk/ low SES: 27	High walk/ high SES: 56 High walk/ low SES:33 Low walk/ high SES: 41 Low walk/ low SES:54	High walk/ high SES: 110 High walk/ low SES:64 Low walk/ high SES: 139 Low walk/ low SES:152	High walk/ high SES: 234 High walk/ low SES:224 Low walk/ high SES: 231 Low walk / low SES:239

GIS, geographic information systems; SES, socioeconomic status.

Table 4 Recruitment methods and rates across 15 International Physical Activity and Environment Study of Adolescents countries

	Australia	Bangladesh	Belgium	Brazil	Czech Republic	Denmark	Hong Kong SAR	India
Recruitment dates	June 2014–December 2015	December 2015–January 2016	September 2014–December 2015	August 2013–June 2014	Spring 2014–October 2015	Fall 2014 + Spring 2015	October 2012–December 2014	February 2015–June 2016
Age range	12–19	11–18	11–17	11–17	12–18	11–16	11–18	12–17
Participant identification	Schools	Schools	a. Previous study participants (n=187) b. Schools (n=188)	Address registry	Schools	Schools	Schools	Door to door based on: a. Direct approach b. Staff/volunteer database c. School database
Participant selection method	Recruited from schools selected in neighbourhoods stratified by SES and walkability	Recruited from schools selected in neighbourhoods stratified by SES and walkability	a. Recruited previous study participants living in neighbourhoods stratified by SES and walkability b. Recruited from schools selected in neighbourhoods stratified by SES and walkability	Recruited directly from residential addresses located in census tracts stratified by SES and walkability	Recruited from schools selected in neighbourhoods stratified by SES and walkability	Recruited from schools selected in neighbourhoods stratified by SES and walkability	Recruited students from schools living in preselected neighbourhoods stratified by SES and walkability	Recruited directly from residential addresses located in neighbourhoods stratified by walkability and SES based on expert judgement Used other methods such as school-based databases
School schedules	Monday–Friday	Saturday–Thursday for most. Morning and afternoon sessions.	Monday–Friday	Morning, afternoon, and/or evening sessions. Some classes on Saturdays	Monday–Friday	Monday–Friday	Monday–Friday	Monday–Friday with classes on some Saturdays and Sundays also.
Incentives	None	None	None	None	None	Drawing for bowling or go-carts with friends (2014), or play equipment for class (2015)	HK$50 for survey; HK$50 for accelerometry	Rs. 750–1000 (US$12–15) gift vouchers
Participation rate	36.3%* 528 consents/1454 presented recruitment packet	Unable to calculate as the number of invited participants is unknown	42.3% *Previous study method*: 187 consents/ 442 eligible contacts *School recruitment method*: unable to calculate as number of invited participants is unknown	61.7% 590 enrolled/956 eligible and accessible contact	89.7% 758 consents/845 invited	16.7% 286 consents/1716 invited	68% 1363 consents/2002 invited	11%; 67% *Staff database method:* 11 agreed/100 approached *School references method*: 113 agreed/ 170 approached *School recruitment method*: unable to calculate as number of invited participants is unknown

	Israel	Malaysia	New Zealand	Nigeria	Portugal	Spain	USA
Recruitment dates	January 2015–January 2016	October 2015–December 2016	September 2014–June 2015	June 2013–April 2014	September 2014–June 2016	April 2013–October 2015	2009–2011
Age range	11–18	12–17	11–18	12–18	11–18	14–18	12–17
Participant identification	Direct approach, snowball	Schools	Schools	Schools	Schools	Schools	Telephone #s from commercial company
Participant selection method	Recruited directly from residential addresses located in neighbourhoods selected to vary on SES and walkability	Recruited from schools in areas stratified by SES and walkability	Recruited from schools in areas stratified by SES and walkability	Recruited from schools selected in neighbourhoods stratified by SES and walkability, then random sampling of students from schools.	Recruited from schools selected in areas stratified by SES and walkability, then random sampling of students from schools.	Recruited from schools in areas stratified by SES and walkability	Recruited directly from randomly sampled residential addresses located in neighbourhoods stratified on SES and walkability, many NH used all available records
School schedules	Sunday–Thursday or Friday. Variable schedules.	Monday–Friday Morning and afternoon sessions.	Monday–Friday	Monday–Friday	Monday–Friday Some students attended school twice a day	Monday–Friday schedule. Some students attended school twice a day	Monday–Friday
Incentives	150 Israeli shekels per individual	RM 30 MYR (in form of T-shirt /meal)	Drawing to receive US$100 shopping voucher/ US$200 voucher for parents	Gift (Souvenirs) worth US$10	None	None	US$40
Participation rate	Unable to calculate as the number of invited participants is unknown	73.3% 440 consents/600 distributed	12.8% 752 consents/5883 invited	42.9% 278 enrolled/ 648 invited	35.7% 240 consents/673 invited	80% Schools chose classrooms. Within classrooms, recruitment rate was 80% on average.	39.6% 1038 enrolled/2619 eligible contacts

*This excludes one visit to a school where the recruitment sheet was not available.
SES, socioeconomic status.

Table 5 Survey measures in International Physical Activity and Environment Study of Adolescents (IPEN Adolescent): description/sample items, response options, subscale scoring and psychometric properties[129–148]

Variable	Reference	Description/sample items	Number of items; response options	Subscale scores used in analyses	Psychometric properties (reference)
Built environment					
Adolescent survey					
Perceived neighbourhood built environment	NEWS-Y-IPEN; adapted from Rosenberg *et al*, 2009[129]	Neighbourhood traffic safety (8 items; eg, so much traffic makes it unpleasant for child to walk in neighbourhood). Neighbourhood crime safety (6 items; eg, high crime rate, unsafe to go on walks at night).	14 items total: 8 items (traffic) and 6 items (crime); 1=strongly disagree, 2=somewhat disagree, 3=somewhat agree, 4=strongly agree	Subscales (11 items retained): Traffic safety: mean of 3 items; 2 reverse coded items Pedestrian infrastructure and safety: mean of 4 items, all reverse coded Safety from crime: mean of 4 items, all reverse coded	Test–retest intraclass correlation coefficients (ICCs)=0.67 and 0.73, respectively (Rosenberg *et al*, 2009[129]) Evidence of construct validity with all subscales (Cerin *et al*, 2019[29])
Parent survey*					
Perceived neighbourhood built environment	NEWS-Y-IPEN; adapted from Rosenberg *et al*, 2009[129]	Neighbourhood traffic safety (8 items; eg, so much traffic makes it unpleasant for child to walk in neighbourhood). Neighbourhood crime safety (6 items; eg, high crime rate, unsafe to go on walks at night). Street connectivity (3 items; eg, many different routes for getting from place to place in neighbourhood). Walking infrastructure (3 items; eg, sidewalks on most streets, grass/ dirt between streets and sidewalks). Neighbourhood aesthetics (4 items; for example, trees along streets, beautiful natural things for child to look at in neighbourhood). Land use mix access (6 items; eg, stores within easy walking distance of home, parking difficult in shopping areas). Land use mix diversity (27 items; eg, how long would it take to walk to various destinations such as supermarket, bus, subway or train stop, small public park). Residential density (6 items; for example, detached single family residences, multifamily houses 4–6 stories).	63 items total; 30 items (traffic, crime, connectivity, infrastructure, aesthetics, access); 1=strongly disagree, 2=somewhat disagree, 3=somewhat agree, 4=strongly agree 27 items (land use mix diversity); 1=1–5 min, 2=6–10 min, 3=11–20 min, 4=21–30 min, 5=31+ min or don't know) 6 items (residential density); 1=none, 2=a few, 3=some, 4=most, 5=all	Subscales (46 items retained): Residential density mean of 6 weighted items; weighting=0, 11, 25, 50, 75 and 100 for items 1–6. Land use mix diversity: mean of 13 items Recreational facilities: mean of 9 items Accessibility and walking facilities: mean of 5 items; 1 reverse coded item Traffic safety: mean of 3 items; 2 reverse coded items Pedestrian infrastructure and safety: mean of 3 items Safety from crime: mean of 4 items, all reverse coded Aesthetics: mean of 3 items	Test–retest ICCs range 0.61–0.78 (Rosenberg *et al*, 2009[129]) Evidence of construct validity with all subscales (Cerin et al., 2019[29])
Physical activity (PA)					
Adolescent survey					
Active transport, to/from school	Adapted from Centers for Disease Control Kids-Walk-to-School programme (CDC, 2000[130])	Number of days travelling both to and from school by walking, bicycling or skateboarding in an average school week. Also asked how long it takes to walk to school.	10 items; To school (5 items) and from school (5 items): Scored 0–5 days. 1 item (# min to walk to school); 1=1–5 min, 2=6–10 min, 3=11–20 min, 4=21–30 min, 5=31+ min.	Total number of active trips per week to and from school were summed (range=0–10 trips).	Test–retest ICCs ranged from 0.51 to 0.92, and % agreement from 73% to 100% (Timperio *et al*., 2006[131]; Joe *et al*., 2012[132]; Cerin *et al*, 2014[96])

Continued

Table 5 Continued

Variable	Reference	Description/sample items	Number of items; response options	Subscale scores used in analyses	Psychometric properties (reference)
PA at school (PE classes)	ActiveWhere, 2005[133]	Number of days per week of PE class, and average length of PE period.	2 items; Scored 0–5 days and open-ended response for # minutes per PE period	Number of days multiplied by length of PE period to represent total time spent in PE during a school week	Test–retest ICCs were from 0.76 to 1.00 and 0.86 to 0.89, respectively. (Joe *et al*., 2012[132]; Cerin *et al*, 2014[96])
Sports and PA classes, at school and outside of school	Adapted from item developed by TEAN investigators	Number of sports teams or physical activity classes (excluding PE) participated in (a) at school and (b) outside of school	2 items; 0=0, 1=1, 2=2, 3=3, 4=4 or more.	Number of teams/ classes used as continuous variable.	Test–retest of original item, ICC=0.65 (Joe *et al*., 2012[132]). Test–retest ICCs for at school and outside school activities 0.74 and 0.89, respectively (Cerin *et al*, 2014[96])
Total PA, outside of school	Prochaska *et al*, 2001[134]	Number of days per week being physically active for at least 60 min outside of PE or gym class (a) during the past 7 days and (b) during a typical week.	2 items; scored 0–7 days	Mean of 2 items to represent average days meeting PA guidelines (60+ min/day)	Test–retest ICC=0.77 and criterion validity r=0.40 (Prochaska *et al*., 2001[134]). Test–retest ICCs during past 7 days and during a typical week 0.70 and 0.79, respectively (Cerin *et al*, 2014[96])
Active transport, non-school (preferred)	Adapted from SMARTRAQ Frank *et al*, 2001[135]	Typical frequency of walking or bicycling to/ from nine locations (eg, recreation facility, friend's house, park, food outlet).	9 items; 0=never, 1=≤once/month, 2=once every other week, 3=once/week, 4=2–3 times/week, 5=4+ times/week.	Mean of 9 items to represent average frequency of active transportation	Test–retest ICCs ranging from 0.47 to 0.82 and % agreement from 57% to 100% (Cerin *et al*, 2014[96])
PA in or near home (preferred)	Sallis *et al*., 1993,[136] ActiveWhere, 2005[133]	Typical frequency of being physically active in seven common settings in or near home (eg, home, nearby street, local park)	7 items; 0=never, 1=≤once/month, 2=once every other week, 3=once/week, 4=2–3 times/week, 5=4+ times/week.	Mean of 7 items to represent the average frequency of being physically active in our near home.	Test–retest ICCs ranged from 0.31 to 0.82 (Joe *et al*., 2012[132]; Cerin *et al*, 2014[96]) and % agreement from 57% to 100% (Cerin *et al*., 2014[96]).
PA in neighbourhood (preferred)	ActiveWhere, 2005[133]	Typical frequency of being physically active in 15 common settings outside of the neighbourhood (eg, recreation centre, fields/ courts, open space).	15 items; 0=never, 1=≤once/ month, 2=once every other week, 3=once/ week, 4=2–3 times/week, 5=4+ times/week.	Mean of 15 items to represent the average frequency of being physically active outside of the neighbourhood.	Test–retest ICCs ranged from 0.39 to 0.66 (Joe *et al*., 2012[132]).
Dog walking (preferred)	Bauman *et al*, 2001[137]	Dog ownership and number of days walking and playing outside with their dog in the last week	3 items; Dog ownership: 1=yes 0=no Number of days (if yes to above): Scored 0–7 days	Number of days used as continuous variable for: 1. walking dog 2. playing with dog	Test–retest Kappa=0.93 (dog ownership). (Joe *et al*., 2012[132]).
PA at school (recess) (preferred)	ActiveWhere, 2005[133]	Frequency and duration of recess periods during a school week. Number of days, number of recess periods per day, and length of time per recess period.	3 items; Scored 0–5 days, open-ended for # recess periods per day, and open-ended for # minutes per recess period	Number of days multiplied by # of recess periods and length of average recess period to represent total time spent in recess during a school week	Test–retest % agreement for number of days=94% and ICC=0.69 for minutes per recess period (Cerin *et al*., 2014[96]).
Parent survey					
Parents' transport walking, leisure PA, and work PA (preferred)	Global Physical Activity Questionnaire (GPAQ); Bull *et al*, 2009[138]	Typical frequency and duration of 1. walking or biking for transport 2. moderate and vigorous PA for leisure 3. moderate and vigorous PA during work	15 items; Categorical (yes/no) for each intensity/ domain. Open-ended # days per typical week and amount of time per typical day for each intensity within each domain of PA.	Number of days per week multiplied by # min/day for each intensity (mod +vig= MVPA) within each domain to create minutes per week of 1. walking/biking for transport 2. minutes of MVPA for leisure 3. minutes of MVPA for work.	Test–retest Kappa (categorical yes/no) ranged from 0.67 to 0.73. Test–retest Spearman's rho for continuous variables ranged 0.67–0.81. Concurrent validity with International Physical Activity Questionnaire (IPAQ), Spearman's rho ranged 0.45–0.57 (Bull *et al*, 2009[138])
Sedentary time					

Continued

Table 5 Continued

Variable	Reference	Description/sample items	Number of items; response options	Subscale scores used in analyses	Psychometric properties (reference)
Adolescent survey					
Time in sedentary behaviours	Marshall *et al*., 2002[139]; Rosenberg *et al*, 2010[140]	Time spent in 6 sedentary activities on a typical school day (non-school hours). For example, watching TV/DVDs/ videos, playing sedentary video games, riding in motor vehicle	6 items; 0=None 1=15 min, 2=30 min 3=1 hour, 4=2 hours, 5=3 hours, 6=4+ hours	Responses recoded to minutes and summed to create min/day engaged in sedentary behaviours	Test–retest ICCs ranged 0.51–0.90, construct validity was good (Rosenberg *et al*., 2010[140]; Cerin *et al*., 2014[96]).
Parent survey					
Parents' total sitting (preferred)	GPAQ; Bull *et al*, 2009[138]	Duration of sitting or reclining per typical day	1 item; open-ended response for # minutes per day	Number of minutes per day used as continuous variable.	Test–retest Kappa=0.68 Concurrent validity with IPAQ, Spearman's rho=0.65 (Bull *et al*, 2009[138])
Parents' time in sedentary behaviours	Rosenberg *et al*, 2010[140]	Time spent in 7 sedentary activities on a typical weekday (non-work hours). For example, watching TV, using internet, riding in motor vehicle	7 items; 0=None 1=15 min, 2=30 min 3=1 hour, 4=2 hours, 5=3 hours, 6=4+ hours	Responses recoded to minutes and summed to create min/day engaged in sedentary behaviours	Test–retest ICCs ranged 0.64–0.90 and good construct validity (Rosenberg *et al*., 2010[140]).
Psychosocial					
Adolescent survey					
Benefits and barriers for PA	Norman *et al*, 2005[141]	Agreement with statements representing barriers and benefits to doing physical activity.	10 items; 1=strongly disagree, 2=somewhat disagree, 3=somewhat agree, 4=strongly agree	To be determined	Test–retest ICCs ranged from 0.68 to 0.86 (Norman *et al*., 2005[141]; Cerin *et al*, 2017[97])
Self-efficacy for PA	Norman *et al*, 2005[141]	Confidence to do physical activity in 6 situations (eg, when have a lot of homework, when feeling sad or stressed)	6 items; 1=I'm sure I can't to 5=I'm sure I can	Mean of 6 items to represent self efficacy to do physical activity	Test–retest ICCs for scale=0.71 and .73 (Norman *et al*., 2005[141]; Cerin *et al*, 2017[97])
Enjoyment of PA	Norman *et al*, 2005[141]	Enjoyment of physical activity	1 item; 1=strongly disagree, 2=somewhat disagree, 3=neutral, 4=somewhat agree, 5=strongly agree	Single item indicator of enjoyment of PA	Test–retest ICCs=0.43 and 0.65 (Norman *et al*., 2005[141]; Cerin *et al*, 2017[97])
Social support for PA	Adapted from Amherst Health & Activity Study; Sallis *et al*, 2002[142]	Social support such as encouragement, participation and transportation provided by adults in household (3 items) and siblings/ friends (2 items).	5 items; 0=never, 1=rarely, 2=sometimes, 3=often, 4=very often	To be determined	Internal consistency alpha=0.75 (Sallis *et al*., 2002[142]; alpha for social support by adults=0.68 and by friends=0.69 (Cerin *et al*., 2017[97]). Test–retest ICCs for social support by adults=0.79 and by siblings/ friends=0.74 (Cerin *et al*, 2017[97])
Rules for PA (preferred)	ActiveWhere, 2005[133]	Presence of parental rules related to physical activity (eg, stay in neighbourhood, do not go places alone, do not ride bike on street)	14 items; 1=yes, 0=no	Sum of 14 items to represent number of rules related to being physically active.	Test–retest ICCs ranged from 0.1 to 0.71 (Joe *et al*., 2012[132]). Test–retest ICC for total score=0.75 (Cerin *et al*., 2017[97])
Pros and cons to reducing sedentary time (preferred)	Norman *et al*, 2004[143]	Agreement with statements representing pros and cons to spending time in sedentary activities.	12 items; 1=strongly disagree, 2=somewhat disagree, 3=somewhat agree, 4=strongly agree	To be determined	Test–retest ICCs ranged from 0.66 to 0.86 (Norman *et al*., 2004[143]; Cerin *et al*, 2017[97])

Continued

Table 5 Continued

Variable	Reference	Description/sample items	Number of items; response options	Subscale scores used in analyses	Psychometric properties (reference)
Self-efficacy to reduce sedentary time (preferred)	Norman *et al*, 2005[141]	Confidence to be able to reduce sedentary time in 7 situations (eg, turn off TV when a programme is on you enjoy, set limits on how long to talk on telephone or text with friends)	7 items; 1=I'm sure I can't to 5=I'm sure I can	Mean of 7 items to represent self-efficacy to reduce sedentary time	Test–retest ICC for scale=0.80 (Norman *et al*, 2005[141]) and 0.59 (Cerin *et al*, 2017[97])
Enjoyment of sedentary time (preferred)	Norman *et al*, 2005[141]	Enjoyment of sedentary time	1 item; 1=strongly disagree, 2=somewhat disagree, 3=neutral, 4=somewhat agree, 5=strongly agree	Single item indicator of enjoyment of being sedentary	Test–retest ICC=0.72 (Salmon *et al*, 2003[144]) and 0.77 (Cerin *et al*, 2017[97])
Sedentary time with others (preferred)	TEAN investigators	Frequency of time spent in sedentary activities such as watching TV or playing electronic games with (a) brother/sisters, (b) parent/guardian/ caregiver, and (c) friends	3 items; 0=never, 1=1–2 days, 2=3–4 days, 3=5–6 days, 4=every hour	To be determined	Test–retest ICC for sedentary time with adults=0.68 and with friends/siblings=0.72 (Cerin *et al*., 2017[97]).
Rules for sedentary time (preferred)	Salmon *et al*, 2005[145]	Presence of parental rules related to sedentary activities (eg, no TV/ computer before homework, no internet without permission)	3 items; 1=yes, 0=no	Sum of 3 items to represent number of rules related to sedentary activities.	Test–retest ICCs ranged from 0.5 to 0.53 (Joe *et al*., 2012[132]). Test--retest ICC for scale=0.80 (Cerin *et al*., 2017[97]).
Other environmental measures					
Adolescent survey					
Home electronics environment	Adapted from ActiveWhere, 2005[133]	1. electronic devices in the bedroom (eg, TV, computer) 2. personal electronics (eg, cell phone, video game player)	6 items (bedroom); 1=yes, 0=no 4 items (personal); 1=yes, 0=no	Sum of 6 items to represent electronic device availability in the bedroom. Sum of 4 items to represent portable personal electronic device availability.	Test–retest ICCs ranged from 0.38 to 0.87 (Rosenberg *et al*, 2010[146]). Test–retest ICCs for devices in bedroom=0.96 and personal electronics=0.78 (Cerin *et al*, 2017[97])
Home workout equipment	ActiveWhere, 2005[133]; adapted from Sallis *et al*, 1997[147]	Frequency of use of workout equipment in the home (eg, bike, basketball hoop, swimming pool)	10 items; 0=not available/do n't have, 1=available but never use, 2=once a month or less; 3=once every other week; 4=once a week or more.	Mean of 10 items to represent average frequency of use of workout equipment in the home.	Test–retest ICCs ranged from 0.49 to 0.75 (Joe *et al*, 2012[132]) and ICC for scale=0.89 (Sallis *et al*, 1997[147]) and 0.98 (Cerin *et al*, 2017[97])
Public transport	TEAN investigators	1. number of days using public transportation (not school commuting) 2. distance travelled away from home without parents by walking, biking and public transit	1 item; Scored 0–7 days 3 items; open-ended for # min from home one way	Number of days/week used as continuous variable. Number of minutes summed for 3 items.	None
Barriers to active school transport	ActiveWhere, 2005[133]	Difficulty of walking or biking to school due to various factors (eg, no sidewalks, too much stuff to carry, too much traffic).	17 items; 1=strongly disagree, 2=somewhat disagree, 3=somewhat agree, 4=strongly agree	Mean of 17 items to represent barriers to active school transport	Test–retest ICCs ranged from 0.38 to 0.77 (Joe *et al*, 2012[132]) Test–retest ICC for scale=0.76 and internal consistency alpha=0.91 (Cerin *et al*., 2017[97])
Barriers to neighbourhood PA (preferred)	ActiveWhere, 2005[133]	Difficulty of being active in local parks or streets/ neighbourhood due to various factors (eg, no equipment, not safe because of traffic, doesn't have good lighting)	9 items; 1=strongly disagree, 2=somewhat disagree, 3=somewhat agree, 4=strongly agree	Mean of 9 items to represent barriers to being active in local parks and streets near home	Test–retest ICCs ranged from 0.35 to 0.71 (Joe *et al*, 2012[132]). Test–retest ICC for scale=0.67 and internal consistency alpha=0.83 (Cerin *et al*., 2017[97]).

Continued

Table 5 Continued

Variable	Reference	Description/sample items	Number of items; response options	Subscale scores used in analyses	Psychometric properties (reference)
After school activity environment (preferred)	ActiveWhere 2005[133]; Durant *et al*, 2009[148]	Frequency of supervised physical activities at school and access to play areas and fields after school.	2 items; 0=never, 1=rarely, 2=sometimes, 3=frequently, 4=always	Mean of 2 items to represent a supportive after school PA environment	Test–retest ICCs were 0.27 and 0.57, respectively (Joe *et al*., 2012[132]) and for the composite 2-item measure 0.70 (Cerin *et al*, 2017[97])

*Adolescents reported on these NEWS items in New Zealand.
MVPA, moderate-to-vigorous physical activity; NEWS-Y, Neighborhood Environment Walkability Scale for Youth; PA, physical activity; TEAN, Teen Environment and Neighborhood Study.

vigorous intensity categories per valid wearing day for (1) total PA, (2) non-school day PA, (3) in-school time PA and (4) total out-of-school time PA. Figure 3 shows each country's average total minutes of MVPA per valid wearing day (values plotted are marginal means that adjusted for any distributional differences in sex or age across countries). Minutes of daily MVPA ranged from 25.8 in India to 59.5 min in the Czech Republic.

BMI and weight status

As noted in online supplemental file 1, in eight countries participants self-reported their height and weight (self-measured or measured during a recent healthcare visit) and in seven countries had their height and weight measured in person by research assistants to provide information needed for BMI calculations (kg/m^2). To have wider international representation of sex-adjusted and age-adjusted standards, the LMS Growth software tool[43] was used, applying the 2007 WHO Child Growth Reference[44] and the International Obesity Task Force (IOTF) cut points.[45 46] The LMS Growth software tool converts physical measurements to SD scores based on the specific growth reference selected and generated IOTF grades.

In IPEN Adolescent, both the sex-adjusted and age-adjusted BMI z-scores (using the 2007 WHO Child Growth Reference) and the IOTF grades will be analysed and reported in manuscripts. The six possible IOTF grades reflect the adjusted BMI values projected to adult age 18 years: thinness grade −3 (BMI <16), thinness grade −2 (BMI 16 to <17), thinness grade −1 (BMI 17 to <18.5), normal weight grade 0 (BMI 18.5 to <25), overweight grade +1 (BMI 25 to <30), or obese grade +2 (BMI 30+).

Demographics and other measures

Adolescents' and parents' demographics and household information taken from surveys were used to assess adolescents' age and sex, parents' years of education and current employment status, annual household income, number of adults, children and licensed drivers in the household, race/ethnicity, marital status, number of work hours/week for adolescents, driver's license for adolescents, automobile ownership and availability for adolescents, and length of time living at the current address. Neighbourhood self-selection by parents was assessed by 18 survey items rating the importance of various reasons for selecting the current neighbourhood (eg, closeness to public transportation, ease of walking, safety from crime). Athletic ability, school grades and weight goals of adolescents were assessed with single survey items.

Built environment measures

Geographic information systems

GIS data included several spatially referenced layers to generate meaningful measures of the built environment. In IPEN Adolescent, environmental variables relevant to PA (eg, residential density, street connectivity, mixed land use, park count, transit density) for each participant's home and school environment were computed in GIS within road network buffers. Road network-based buffers of different sizes (500 m and 1000 m to match the IPEN Adult study buffers) were created in GIS around each participant's home and school. A separate analysis was conducted to determine which buffer method resulted in the greatest ability to explain objectively measured PA, resulting in the selection of a trimmed 'sausage buffer' method.[47] These buffers define areas that can be reached on the road network, but exclude areas that were not accessible due to a major barrier (eg, freeway, river, train, or steep terrain). Two additional buffer sizes (250 m and 2000 m) were calculated in some countries for exploratory analyses to determine optimal buffer sizes and whether they might differ across countries.

IPEN Adolescent GIS innovations to enhance applicability to adolescents were measures created by building on the 'playability index' concept[48] consisting of proximity and density of public and private recreation facilities, and simultaneously examining school neighbourhood and home neighbourhood environments to improve explanation of outcomes. While characteristics of local neighbourhoods including walkability, greenspace and pedestrian environment features have been linked with PA or sedentary time from travel[49] and green space,[50] regional location and access to destinations determines the amount of time and effort required for commuting and to meet other needs. Regional accessibility further captures the difference of being on the edge or in the middle of a given town, city or region. Regional accessibility is a well-established concept in the transportation literature and is designed to measure time-based

Table 6 Geographic information systems (GIS), Microscale Audit of Pedestrian Streetscapes (MAPS) Global, GPS, accelerometer data availability across 15 International Physical Activity and Environment Study of Adolescents (IPEN Adolescent) countries

	Australia	Bangladesh	Belgium	Brazil	Czech Republic	Denmark	Hong Kong SAR	India	Israel	Malaysia	New Zealand	Nigeria	Portugal	Spain	USA
GIS (individual variables in participant-based buffers)	Y	N	Y	Y	Y	Y	Y	N	Y	N	Y	N	Y	Y	Y
MAPS Global pedestrian audit data collected (subsample)	N	N	Y	Y	N	N	Y	Y	N	Y	N	Y	N	Y	Y
GPS data collected	Y	N	Y	Y	Y	Y	Y	Y	N	N	Y	N	Y	N	Y
Number of participants with GPS data (matched with accelerometer data)	n=331	N/A	n=180	n=76	n=170	n=201	Unknown at this time	n=324	N/A	N/A	n=196	N/A	n=147	N/A	n=339
Number of participants with accelerometer data (8+ wearing hour per day)	1+ day: n=412 4+ days: n=372	1+ day: n=92 4+ days: n=90	1+ day: n=244 4+ days: n=224	1+ day: n=456 4+ days: n=419	1+ day: n=128 4+ days: n=105	1+ day: n=169 4+ days: n=126	1+ day: n=549 4+ days: n=549	1+ day: n=316 4+ days: n=315	1+ day: n=224 4+ days: n=223	1+ day: n=404 4+ days: n=325	1+ day: n=501 4+ days: n=500	1+ day: n=260 4+ days: n=245	1+ day: n=161 4+ days: n=143	1+ day: n=373 4+ days: n=373	1+ day: n=885 4+ days: n=843

N, no; Y, yes.

or distance-based variations in access to opportunities. Transportation planners use this indicator to determine how contrasting infrastructure investments impact travel choices, vehicle dependence, greenhouse gas emissions and transit ridership.[51] The international context of the IPEN Adolescent study required using a distance-based approach in order to derive a comparable and consistent measure of regional accessibility across all study sites.

Eleven of the 15 countries have GIS data to describe the built environment. The quality and comparability of the GIS measures across countries were systematically assessed, and only the comparable variables will be included in pooled analyses. Details about the comparability assessment can be found in the Coordinating centre: quality control and comparability of methods section. Table 7 outlines the GIS variables in the pooled dataset.

Microscale pedestrian environment: MAPS Global

MAPS Global is a structured observation/audit tool developed to assess microscale environmental features such as sidewalks, trees and shade, and street crossing amenities along streets between participant homes and commercial centres (ie, likely walking paths towards neighbourhood destinations). Microscale measures of the environment capture attributes related to the pedestrian experience at a finer scale compared with the GIS-based built environment measures described above.[38] Microscale features of the neighbourhood environment have been found to be related to walking and biking for transportation in numerous age groups, including adolescents.[52]

The MAPS Global instrument was adapted from the reliable and validated US-based MAPS tool[38 52] with contributions from eight additional tools developed in different countries.[53–60] IPEN Adolescent investigators provided input into development of MAPS Global items to ensure the instrument captured important PA-related environmental features for each continent. Evaluation of inter-rater reliability data collected in five countries showed 'good' to 'excellent' reliability for all items and scales.[61]

In IPEN Adolescent, eight countries collected MAPS Global data for 100 randomly selected participants (25 in each walkability-by-SES neighbourhood type). Data were collected by trained and certified observers along a 400–800 m road network route from participant homes toward the nearest commercial block. MAPS-Global has six main sections: destinations and land use (eg, grocery/supermarkets, restaurants, parks), streetscapes (eg, transit stops, traffic calming), aesthetics and social disorder (eg, landscaping, graffiti), street segments (sidewalks, tree coverage, building setbacks), street crossings (eg, intersection control, signalisation, crosswalks), and cul-de-sacs/dead ends (distance to home, amenities). When multiple street segments, crossings and cul-de-sacs occurred within a route, the respective variables were averaged. A tiered scoring system was developed that grouped items into subscales to create positive and negative section scores. An overall grand score will be calculated that subtractsthe overall negative from the overall positive. Additional

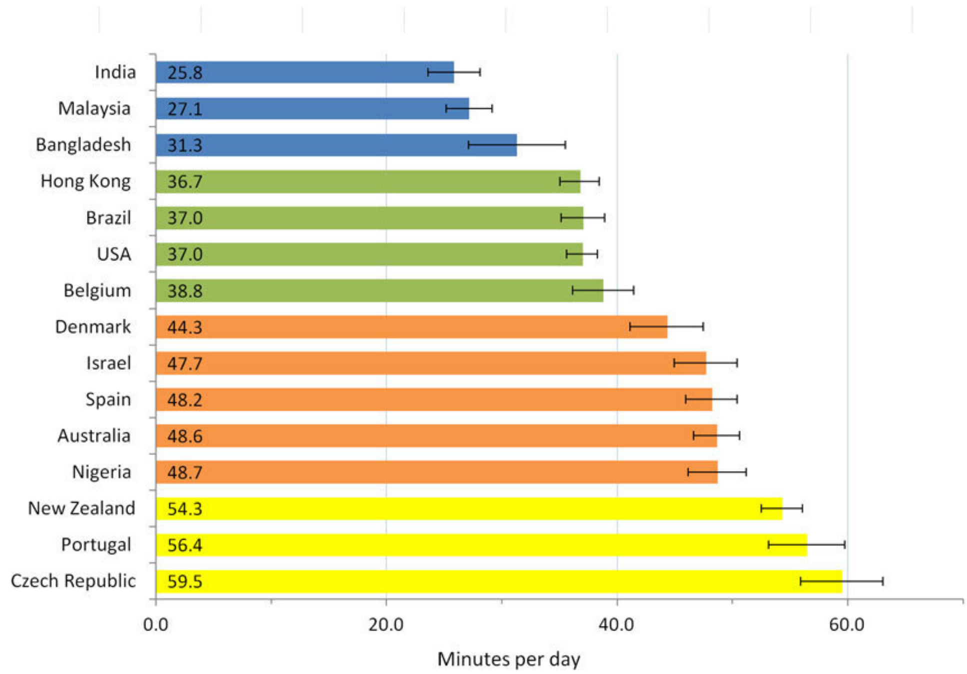

Figure 3 Average total daily accelerometer-measured moderate-to-vigorous physical activity across 15 International Physical Activity and Environment Study of Adolescents countries (age and sex adjusted).

grand scores conceptually related to walking/biking for transport and leisure time PA will be created. Cross-domain subscales will be created to capture pedestrian infrastructure, pedestrian design, bicycling facilities and pedestrian safety. Details about item coding and subscale creation can be downloaded (https://drjimsallis.org/measure_maps.html#MAPSGLOBAL).

Global positioning system

In 10 countries, at least a subsample of adolescents were also asked to wear a Qstarz BT-Q1000xt or Holux RCB-300 GPS tracker. The GPS tracker was placed on the same belt as the accelerometer, and participants were instructed to charge it every day. The GPS devices were set to collect longitude, latitude and altitude every 30 s and all data were timestamped. The QStarz BT-Q1000xt GPS trackers are commonly used in PA studies and have a small median dynamic positional error of 2.9 m.[62] All GPS data, together with the matching accelerometer data, were cleaned (removing GPS points with excessive changes in speed or altitude) and merged using the Personal Activity and Location Measurement System[63] (PALMS; PALMS is no longer available but has been incorporated in a new system, HABITUS, www.habitus.eu) to match the two types of data based on their timestamp. PALMS was also used to identify trips and classify transportation mode (walking, biking and motorised transportation) based on setting the 90th percentile upper speed thresholds for walking at 10 km/hour and for cycling at 35 km/hour.[64]

The main purpose of collecting the GPS data was to create device-based domain-specific PA and sedentary behaviour measures. Using a custom-build PostgreSQL database and a series of SQL scripts,[65] the following domains were identified: home, school, home-neighbourhood, school-neighbourhood, transport and 'other'. All combined accelerometer and GPS datasets were imported into the PostgreSQL database, together with GIS data on home and school addresses as well as the home and school neighbourhoods for each individual participant. Home and school addresses were buffered by 100 m to create a polygon for home and school, respectively. Each GPS point was assigned to one of the mutually exclusive domains. For each of the domains, the following daily variables were created for each participant: duration (ie, how much time was spent in a domain), accelerometer wear time, sedentary time, time spent in light PA, time spent in moderate PA, time spent in vigorous PA, time spent in MVPA, average accelerometer count per minute. GPS n's by country can be found in table 6.

By selecting all data on trips in combination with the home and school address in the PostgreSQL database, device-based measures of travel to and from school were created, distinguishing walking and cycling from motorised transportation.

Coordinating centre: quality control and comparability of methods

Systematic guidance to participating countries was provided by the San Diego CC and international Executive Committee on all aspects of study design, measures and data collection methods, and how to provide data to the CC for creating pooled datasets for analyses. Manuals, protocols, trainings and consultation were provided to countries on accelerometer wearing, data collection, and management to facilitate common methods for increasing wear-time compliance and standardising data screening procedures. Sample surveys with 'required' and

Table 7 Geographic information systems (GIS) variables used in International Physical Activity and Environment Study of Adolescents (IPEN Adolescent)

GIS construct	Description	Calculation
Residential Density		
Density	Net residential density	Dwelling unit count/land area of buffer in square kilometres (km^2)
Intersection density		
Density	Intersection density	Intersection count/land area of buffer (km^2)
Public transit		
Counts	Transportation count for all types of public transit	Transit counts (any type)
Density	Transportation density for all types of public transit	Transit counts (any type)/land area of buffer (km^2)
Distance	Distance to nearest public transit of any type	Street network distance in metres
Parks		
Counts	Number of parks contained within or intersected by buffer	Park count (any size of park)
Area	Park area contained within or intersected by buffer	Park area (any size of park) in metres
Density	Park density	Park count (any size)/land area of buffer (km^2)
Distance	Distance to nearest park of any size	Street network distance in metres
Private recreation		
Counts of parcels	Number of recreation land use parcels	Private/public recreation parcel counts
Density of parcels	Recreation parcel density	Private/public recreation parcel count/land area of buffer (km^2)
Counts of facilities	Number of private recreation facilities	Private recreation facilities counts
Density of facilities	Private recreation facilities density	Private recreation facilities count/ land area of buffer (km^2)
Distance to facility	Distance to nearest private recreation facility	Street network distance in metres
Land use mix		
Parcel counts (three uses)	Number of commercial/retail, food and entertainment parcels	Commercial/retail, food and entertainment parcel counts
Ratio of parcels to dwelling counts (three uses)	Ratio of commercial/retail, food and entertainment parcels to the number of dwelling units	Commercial/retail, food and entertainment parcel counts/dwelling unit counts
Ratio of land area to residential land area (three uses)	Ratio of commercial/retail, food and entertainment land area to residential land area	Commercial/retail, food and entertainment land area/residential land area
Ratio of parcels to residential land area (three uses)	Ratio of commercial/retail, food, and entertainment parcels to commercial/retail, food, and entertainment land area	Commercial/retail, food and entertainment parcel counts/commercial/retail, food and entertainment land area
Parcel counts (four uses)	Number of commercial/retail, food, entertainment and office parcels	Commercial/retail, food, entertainment and office parcel counts
Ratio of parcels to dwelling counts (four uses)	Ratio of commercial/retail, food, entertainment and office parcels to the number of dwelling units	Commercial/retail, food, entertainment and office parcel count/dwelling unit counts
Ratio of land area to residential land area (four uses)	Ratio of commercial/retail, food, entertainment and office land area to residential land area	Commercial/retail, food, entertainment and office land area/residential land area

Continued

Table 7 Continued

GIS construct	Description	Calculation
Ratio of parcels to residential land area (four uses)	Ratio of commercial/retail, food, entertainment and office parcels to commercial/retail, food, entertainment and office land area	Commercial/retail, food, entertainment and office parcel counts/ commercial/retail, food, entertainment and office land area
Parcel counts (five uses)	Number of commercial/retail, food, entertainment, office, and civic parcels	Commercial/retail, food, entertainment, office and civic parcel counts
Ratio of parcels to dwelling counts (five uses)	Ratio of commercial/retail, food, entertainment, office, and civic parcels to the number of dwelling units	Commercial/retail, food, entertainment, office and civic parcel counts/dwelling unit counts
Ratio of land area to residential land area (five uses)	Ratio of commercial/retail, food, entertainment, office, and civic land area to residential land area	Commercial/retail, food, entertainment, office and civic land area/residential land area
Ratio of parcels to residential land area (five uses)	Ratio of commercial/retail, food, entertainment, office, and civic parcels to commercial/retail, food, entertainment, office, and civic land area	Commercial/retail, food, entertainment, office and civic parcel counts/commercial/ retail, food, entertainment, office and civic land area
Regional accessibility		
Distance	Distance to nearest downtown/centre city	Street network distance in metres
Distance	Distance to nearest major transit hub	Street network distance in metres
Distance	Distance to nearest to largest university	Street network distance in metres
Distance	Distance to nearest largest hospital	Street network distance in metres
Distance	Distance to nearest largest employment centre	Street network distance in metres
Distance	Distance to nearest largest natural/open space feature	Street network distance in metres
Distance	Distance to nearest major shopping centre	Street network distance in metres
Distance	Distance to nearest major employment centre	Street network distance in metres

All variables calculated for four buffer sizes (250 m, 500 m, 1 km, and 2 km) and for residential and school buffers. For most variables, 500 m and 1 km buffer sizes are considered primary variables, and 250 m and 2 km buffer sizes are considered secondary variables. Fewer countries have the secondary variable so they will not be prioritised for most IPEN Adolescent papers. All variables calculated using street network buffers with the sausage buffer calculation method.

'desired' items were provided to countries that specified question wording and response option coding. Surveys and back translations (if needed) were sent to the CC by each country. Multiple methods were employed to ensure quality and comparability of survey data collected across countries that included: (1) independent assessment of content comparability of survey items, (2) double checks on and standardisation of item-level response coding, (3) additional harmonising as needed of response options and coding for comparability of data across countries and (4) further examination of data received by the CC to identify outliers and invalid responses as part of cleaning and quality controls for compilation of master pooled datasets for use in analyses.

A similar quality control process was used with GIS variables. Initially, each country completed IPEN Adolescent GIS templates to precisely describe the availability of and access to GIS data in their country, so the possibilities for specific built environment measures and methodologies could be determined. This information was reviewed for the purpose of producing comparable variables across countries. The templates defined and operationalised a common set of built environment constructs (eg, residential density), variables, procedures, and standardised variable names (templates available at: http://www.ipenproject.org/documents/methods_docs/IPEN_GIS_TEMPLATES.pdf). On completion of their GIS work, countries submitted their GIS datasets to the CC. Two GIS experts will review variables and data from each country, judge deviations from the countries' templates, request clarifications or revisions, and only accepte comparable GIS measures for the pooled analyses. However, variations in computation of GIS variables will still exist across countries, so comparability will not be exact.

Analysis plans

Generalised additive mixed models (GAMMs) with random intercepts and appropriate variance and link functions will be used to estimate pooled associations and address the study aims. GAMMs will be used because they can account for various sources of dependency in the data, model curvilinear relationships of unknown form and model data with different distributional assumptions, such as dichotomous (obese vs not obese) and positively skewed continuous variables (eg, weekly minutes of MVPA).[66 67] Specifically, GAMMs with random intercepts will model dependency in the data arising from the fact that each IPEN Adolescent site employed a two-stage sampling strategy to recruit participants from preselected AUs and/or schools (table 3). Because adolescents living in the same AU could attend different schools and adolescents attending the same school could reside in different AUs, AUs and schools will be modelled as second-level crossed random factors. In contrast, cities/geographical locations will be treated as fixed factors because their number is small, and they represent a convenience rather than a random sample of cities.

We will routinely examine whether associations between exposures and outcomes differ by study site and adolescent sex by adding appropriate two-way interaction terms to the corresponding main-effect GAMMs (see Gidlow *et al*, 2019[68] for an example of the analytical approach). The same procedure will be adopted to identify other theoretically plausible moderators of associations (eg, SES). Significant interaction effects, determined by comparing the Akaike Information Criterion values of GAMMs with and without an interaction term, will be probed by estimating associations at meaningful values of the moderator (eg, males and females; each study site).

The mediating effects of objectively measured MVPA and sedentary behaviour on the relation between (objective and reported) environment attributes and overweight/obesity status will be estimated using the joint-significance test.[69 70] This entails estimating the association between an exposure and a mediator, and the exposure-adjusted association between the mediator and an outcome. If both associations are statistically significant, the presence of a significant mediating effect is confirmed.

If more than 5% of participants included in the analytical sample have missing data on at least one of the examined variables, multiple imputations will be performed, and the analyses will be conducted on 100 imputed datasets. Analyses based on complete data only when missing data are missing at random (ie, when missingness is related to other variables included in the study) can yield biased results, while analyses based on properly conducted multiple imputations do not.[71] Multiple imputations will be performed using chained equations[72] accounting for within-site administrative-unit-level and school-level crossed cluster effects arising from the two-stage stratified sampling strategy employed in each study site. Sensitivity analyses will be conducted to compare the results of the analyses performed on imputed data with those based on cases with complete data only. Significant discrepancies between the results of these analyses will be reported.

ETHICS AND DISSEMINATION

Investigators in all 15 countries were responsible for obtaining approvals and assuring compliance with their own Institutional Review Board ethical requirements for their in-country studies (online supplemental table 3). The IPEN Adolescent study and San Diego-based CC activities to produce the deidentified pooled dataset were approved by the Institutional Review Boards at San Diego State University and the University of California San Diego, where the lead investigators who obtained the grant were located. Informed assent by adolescents and consent by parents were obtained for all participants. There are no known health risks or problems associated with wearing accelerometers. We advised participants that they may wear the device under their clothing on a belt we provided to minimise drawing attention to the device and any potential embarrassment while wearing it. Participants were informed they may refuse to answer any question they were not comfortable with. No personally identifiable information was uploaded to the CC for the pooled datasets, and all participants are identified by a unique participant study code. Address-based GIS variable creation was conducted in each country, and no address information was transmitted to the CC. All data are kept private and confidential.

The main study priority is to analyse the data and report results in peer-reviewed journals. The Publication Committee, led by Erica Hinckson of Auckland University of Technology, has developed a publication plan to systematically analyse the data to address study aims while minimising overlap across papers submitted for publication. The goal is for each principal investigator to lead at least one paper based on pooled analyses. We intend to publish in high-impact international medical, psychology, urban planning, geography, and/or public health peer-reviewed journals. Ester Cerin of Australian Catholic University (ACU, Melbourne) will provide oversight and conduct data analyses along with a group of analysts that she will oversee.

The IPEN Adolescent website provides access to protocols, surveys, training materials and publications (http://ipenproject.org/IPEN_adolescent.html). Investigators throughout the world can use these materials to collect data in their countries that can be used for local scientific and advocacy purposes, using IPEN Adolescent data as a point of comparison.

The ultimate goal of the IPEN Adolescent study is to use the results to stimulate and guide actions to create more activity-supportive environments worldwide. Activity-supportive environments have a wide range of societal benefits, including health, environmental sustainability, and economic development.[73 74] Activity-supportive environments can be advocated for to help achieve international non-communicable disease action plans,[75] sustainable development goals[76] and PA action plans.[77] IPEN Adolescent investigators will be encouraged and assisted to take specific actions to communicate results to practitioners and policy decision-makers in a wide variety of sectors, such as public health, paediatrics, city planning, transportation, parks and recreation, environmental protection, and economic development.[78] Evidence and recommendations will be communicated via lay summaries and infographics, webinars, press releases, public testimony and meetings with policy-makers and advocacy organisations.

DISCUSSION

Built environment improvements to support PA for transportation and leisure purposes are widely recommended as evidence-based strategies[78] with the WHO's Global Action Plan for Physical Activity[77] being a prominent recent example. Though extensive evidence supports such recommendations, the evidence is both less plentiful and consistent for some populations, such as children and adolescents, older adults, and residents of low-income and middle-income countries.[18] The IPEN Adolescent Study was designed to provide internationally relevant evidence about the relation of built environments to PA, sedentary behaviour and overweight/obesity among a less-studied population group. There is a particular need to develop evidence that can guide more effective population-level improvements in adolescent PA. Adolescents are of particular interest because in virtually all countries with prevalence data, about two-thirds do not meet PA guidelines,[79] obesity rates in this age group are high and rising,[1] and PA declines during adolescence.[80] IPEN Adolescent will contribute rare data about built environments and PA in low-income and middle-income countries. Planned analyses will specifically examine consistency of findings across countries to reveal whether patterns of association differ by country-income level.

IPEN Adolescent will add substantially to the few international studies of built environments and PA. Though the study was based partly on the IPEN Adult study that has produced notable findings,[81 82] IPEN Adolescent improves the methods by including countries with more diversity of income and geography, such as low-income countries, more Asian countries, and countries from Africa and the Middle East. IPEN Adolescent expands the range of environmental variables studied, with additional GIS-based variables such as regional accessibility, improved assessment of recreation facilities, observations of both streetscapes and parks, and use of GPS monitoring that allows assessment of location of PA and sedentary behaviour. The only other similar international study we are aware of is the International Study of Childhood Obesity, Lifestyle and the Environment study of younger children, which had the strengths of including primarily low-income countries, using accelerometers, and collecting dietary data. Because the countries were low-income, GIS data were not available.[60]

The IPEN Adult study showed surprising similarity of associations across 12 diverse countries.[82] The IPEN Adolescent study includes even more diverse countries and should be able to provide a robust evaluation of the generalisability of results across countries. The diversity of the country context was documented on several important dimensions in table 1. For example, the per capita income in Hong Kong was over 15 times higher than that of Bangladesh. Car ownership ranged from 4 per 1000 in Bangladesh to 860 in New Zealand. Life expectancy ranged from 54.8 years in Nigeria to 84.8 years in Hong Kong.

All 15 countries contributed accelerometer data that will be used in pooled analyses. The quality of the accelerometer data collection protocol, including requests for rewear, is indicated by the finding that 94% of those with any days of wearing completed 4 days of wearing, which is a reliable estimate of weekly MVPA.[83] The common accelerometer protocols permits examination of MVPA across countries, as shown in figure 3, as well as other intensities of PA. It is notable that in all countries, mean MVPA was less than the recommended 60 min/day.[84] In the two Asian countries with the lowest means, the average was less than 30 min per day. Thus, there was a twofold difference between the least-active and most-active adolescent samples. These results support the need for studies that provide evidence that can lead to interventions designed to create long-term, population-wide PA increases among adolescents worldwide.

Building on the lessons of using GIS data in IPEN Adult, GIS data in the present study were expanded to include other types of neighbourhoods (ie, school as well as home neighbourhood), different methods to calculate some variables (ie, land use mix), and a wider range of environmental variables (ie, private recreation facilities, regional accessibility). Though limitations remain with the quality, recency, completeness and comparability of GIS data, the available variables should strengthen explanation of outcome variables beyond what was possible previously. The detailed GIS methodological templates both guide and document steps in creating variables so the present methods are transparent and should be useful to other investigators.[85]

The credibility of IPEN Adolescent results should be enhanced by the use of several relatively objective measures that complement and enhance the extensive self-report measures. All 15 countries used accelerometers, 11 countries had GIS data, 10 countries provided GPS data on subsamples, and 8 countries conducted MAPS Global audits on streets near the homes of a subsample of adolescents. The self-reported data on neighbourhood environments, PA, sedentary behaviours and psychosocial variables, in combination with the rich objective data, should allow greater explanation of outcomes than has been possible in past studies.

IPEN Adolescent has already made contributions in building research capacity and developing environmental measures, both of which can facilitate expansion of built environment research worldwide. CC staff conducted online trainings in complex measures and offered ongoing technical assistance in all measures by telephone and email for training and quality control purposes. Detailed accelerometer protocols and interactive GIS templates were designed to build skills and enhance quality and comparability of measures. Though the NEWS self-report environment surveys have been widely used internationally, they were developed in the USA, so substantial adaptations were needed to reflect the range of international environmental attributes, and internationally comparable scoring protocols were developed.[29] IPEN Adolescent investigators were involved in the development and evaluation of versions of the NEWS for Africa,[86 87] India[88 89] and Europe.[90] The MAPS Global streetscape observation measure was developed and evaluated by IPEN Adolescent investigators for use in the study,[61] and we hope this measure will be used by other researchers worldwide.

Challenges and limitations

Despite efforts to promote common methods, this was not possible for several components of the design and methods. The original design was to select adolescents from neighbourhoods stratified by high/low walkability and high/low SES. There were numerous deviations from this approach, mainly due to feasibility considerations or data limitations. Though the specific procedures varied, all countries took specific steps to maximise variation in built environments and SES, which was the underlying goal of the design. As presented in the distribution of participants across quadrants in table 3, only a few countries have notable imbalances in sample sizes across quadrants, so confounding of walkability and SES should not be an issue in the pooled analyses. The methodological variations in neighbourhood selection will not compromise analyses, because built environment and SES variables will be examined as individual-level continuous variables, and comparisons across study design quadrants will not be made.

Recruitment rates varied substantially across countries (13% in New Zealand to 90% in Czech Republic), but this was not surprising given the differences in recruitment approaches across sites, modes of communication and incentives used. A few countries were not able to estimate recruitment rates due to the role played by partners or because they used a variety of approaches. Very high recruitment rates were not expected, because surveys were lengthy, both parents and adolescents had to participate, adolescents had to wear accelerometers for 1 week plus GPS devices in about half the countries, and many countries were not able to provide incentives, often due to human subjects protection rules. Though some unquantified degree of selection bias must be acknowledged, we believe the documented diversity of participants within and across countries will allow much more generalisability of findings than is justified in single-country studies.

In addition to several countries lacking GIS data, there were limitations to quality and comparability. Spatial data on parcels was almost always available, but not the footprint or total floor area of buildings. Land use categories varied substantially across countries, so only general categories can be used, such as commercial or residential. When the category is 'mixed use', the mix of uses is rarely known. Parks and public transport stops/stations are defined differently across countries. Variables of particular interest, such as sidewalks, street crossing characteristics and bicycle facilities are rarely available in GIS. These limitations are expected to bias findings toward underestimating effect sizes when using GIS.

The absence of measures of school ground environments, programmes, and policies is a limitation of the study. School-based measures were considered important influences on adolescent behaviour, but they were not required measures due to the infeasibility of measuring many schools in some countries. For future studies, it would be valuable to examine the separate and combined effects of multiple environmental settings, including neighbourhood, school, park and private recreation settings.

The most fundamental limitation of IPEN Adolescent was the cross-sectional design, which cannot provide evidence of causality. Though literature reviews routinely recommend more longitudinal and quasi-experimental studies in the built environment field,[91] there are important contributions that can be made by cross-sectional studies. Promising cross-sectional findings provide a rationale for larger investments in prospective studies. Methods validated in cross-sectional studies can be used to evaluate 'natural experiments' of environmental change. The shape (ie, linear, non-linear) and generalisability of associations across countries/cities provide hypotheses that can be used to tailor interventions for each site.

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